# FILTER AKTIF

***Low Pass Filter***
**(LPF)**

***High Pass Filter***
**(HPF)**

***Band Pass Filter***
**(BPF)**

***Band Stop Filter***
**(BSF)**

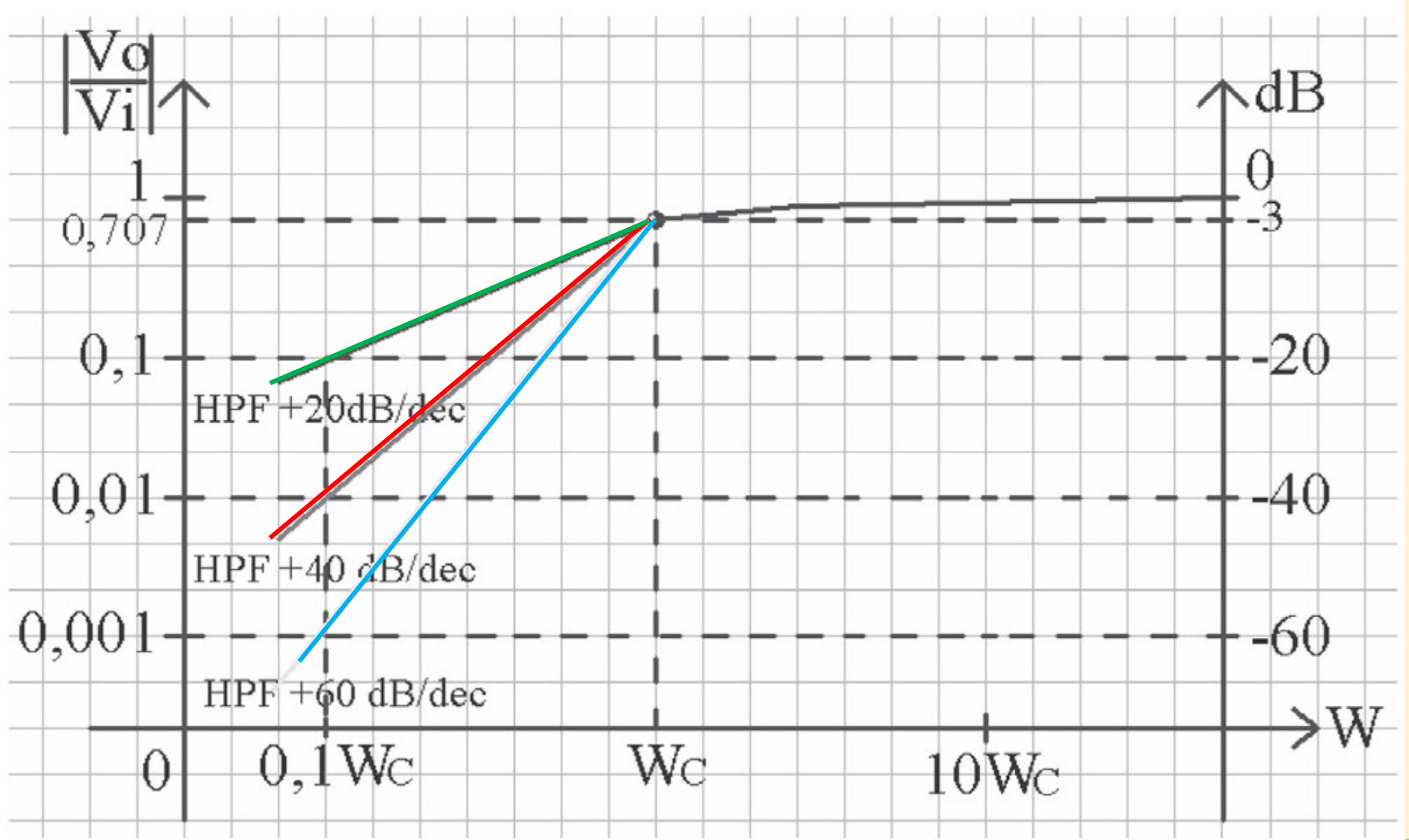
# *High Pass Filter*
# (HPF)

**HPF +20 dB/dec** adalah HPF yang penguatannya naik sebesar 20 dB apabila frekuensinya naik sebesar 10 kali atau satu decade. Pada saat frekuensi sinyal input sama dengan frekuensi *cut-off* ($\omega_c$) maka penguatannya sama dengan (1/) atau 0,707 dan sudut phasenya sebesar $+45^o$.

**HPF +40 dB/dec** adalah HPF yang penguatannya naik sebesar 40 dB apabila frekuensinya naik sebesar 10 kali atau satu decade. Pada saat frekuensi sinyal input sama dengan frekuensi *cut-off* ($\omega_c$) maka penguatannya sama dengan (1/) atau 0,707 dan sudut phasenya sebesar $+90^o$.

**HPF +60 dB/dec** adalah HPF yang penguatannya naik sebesar 60 dB apabila frekuensinya naik sebesar 10 kali atau satu decade. Pada saat frekuensi sinyal input sama dengan frekuensi *cut-off* ($\omega_c$) maka penguatannya sama dengan (1/) atau 0,707 dan sudut phasenya sebesar $+135^o$.

# Tanggapan Frekuensi pada HPF Real



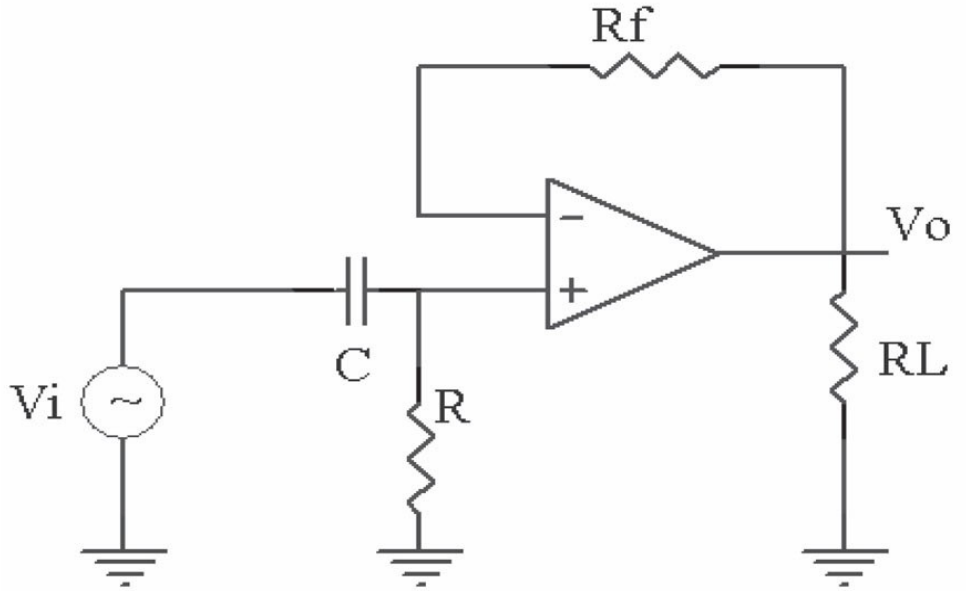
# Rangkaian HPF +20 dB

$$V_o = \frac{R}{Z_c + R}.Vi$$

$$V_o = \frac{R}{\frac{1}{j\omega.C} + R}.Vi$$

$$\frac{Vo}{Vi} = \frac{1}{1 + \frac{1}{j\omega.C.R}} \quad \text{... (6.23)}$$

$$\omega_c = 2\pi f_c$$




**Gambar 6.4** *Rangkaian HPF +20 dB/de*

Pada HPF +20 dB/dec bahwa pada $\omega = \omega_c$ maka nilai $\left|\frac{Vo}{Vi}\right| = \frac{1}{\sqrt{2}} = 0{,}707$ dan sudut phasenya . Supaya menghasilkan nilai seperti itu maka nilai pada penyebut pada persamaan (6.23) adalah $\left|1 + \frac{1}{j\omega.C.R}\right| = \sqrt{2}$

sehingga $\frac{1}{\omega_c.C.R} = 1$ atau $\omega_c = \frac{1}{C.R}$ atau $C = \frac{1}{\omega_c.R}$

$$\frac{1}{\omega_c . C . R} = 1 \text{ atau } \omega_c = \frac{1}{C . R} \text{ atau } C = \frac{1}{\omega_c . R}$$

$$\frac{Vo}{Vi} = \frac{1}{1 + \frac{1}{j\omega . C . R}} = \frac{1}{1 + \left( \frac{\omega_c}{j\omega} \right)} = \frac{1}{1 - j\left( \frac{\omega_c}{\omega} \right)}$$

Nilai penguatan $\left|\frac{Vo}{Vi}\right|$ dan sudut phase θ untuk beberapa nilai ω yang berbeda adalah

**Tabel 6.4** *Nilai penguatan dan sudut phase HPF +20 dB/dec*

| No. | Frekuensi (ω) | Penguatan ($\left\|\frac{Vo}{Vi}\right\|$) | Sudut phase (θ) |
|---|---|---|---|
| 1 | $0{,}1\omega_c$ | 0,0995037190 | +84,29° |
| 2 | $0{,}25\omega_c$ | 0,2425356250 | +75,96° |
| 3 | $0{,}5\omega_c$ | 0,4472135955 | +63,43° |
| 4 | ωC | $\frac{1}{\sqrt{2}}$ atau 0,707 | +45° |
| 5 | $2\omega_c$ | 0,8944271909 | +26,56° |
| 6 | $4\omega_c$ | 0,9701425001 | +14,04° |
| 7 | $10\omega_c$ | 0,9950371902 | +5,71° |

## Contoh 6.8

Hitunglah frekuensi *cut-off* ($\boldsymbol{\omega}_c$) pada Gambar 6.4 nilai R=10K, C=10µF, Rf=100K,RL=10K.

Apabila **Vi**=100sin($\boldsymbol{\omega}$.t+30$^o$)$mV$, hitunglah Vo pada frekuensi 1 rad/s, 5 rad/s, 10 rad/s, 20 rad/s, 100 rad/s.

$$\omega_c = \frac{1}{CR}$$ *ut-c*

$$\omega_c = \frac{1}{10^{-5}.10^{4}} = 10\,\text{rad/s}$$

Untuk $\omega = 1 rad/s$,

$$\left|\frac{Vo}{Vi}\right| = \frac{1}{1 - j\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1 - j\left(\frac{10}{1}\right)} = \frac{1}{1 - j10} = \frac{1}{\sqrt{1^2 + (-10)^2}} = 0{,}099$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{-10}{1}\right)} = \frac{0°}{-84{,}29°} = 0° + 84{,}29° = +84{,}29°$$

$$Vo = (0{,}099).100\sin(1.t + 30° + \theta) = 9{,}9\sin(1.t + 114{,}29°)mV$$

Untuk $\omega = 5 rad/s$,

$$\left|\frac{Vo}{Vi}\right| = \frac{1}{1 - j\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1 - j\left(\frac{10}{5}\right)} = \frac{1}{1 - j2} = \frac{1}{\sqrt{1^2 + (-2)^2}} = 0{,}447$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{-2}{1}\right)} = \frac{0°}{-63{,}43°} = 0° + 63{,}43° = +63{,}43°$$

$$Vo = (0{,}447).100\sin(5.t + 30° + \theta) = 44{,}7\sin(5.t + 93{,}43°)mV$$

Untuk $\omega = 10 rad/s$,

$$\left|\frac{Vo}{Vi}\right| = \frac{1}{1 - j\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1 - j\left(\frac{10}{10}\right)} = \frac{1}{1 - j1} = \frac{1}{\sqrt{1^2 + (-1)^2}} = \frac{1}{\sqrt{2}} = 0{,}707$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{-1}{1}\right)} = \frac{0°}{-45°} = 0° + 45° = +45°$$

$$Vo = (0{,}707).100\sin(10.t + 30° + \theta) = 70{,}7\sin(10.t + 75°)mV$$

Untuk $\omega = 20 rad/s$,

$$\left|\frac{Vo}{Vi}\right| = \frac{1}{1 - j\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1 - j\left(\frac{10}{20}\right)} = \frac{1}{1 - j0,5} = \frac{1}{\sqrt{1^2 + (-0,5)^2}} = 0,894$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{-0,5}{1}\right)} = \frac{0°}{-26,56°} = 0° + 26,56° = +26,56°$$

$$Vo = (0,894).100\sin(20.t + 30° + \theta) = 89,4\sin(20.t + 56,56°)mV$$

Untuk $\omega = 100 rad/s$,

$$\left|\frac{Vo}{Vi}\right| = \frac{1}{1 - j\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1 - j\left(\frac{10}{100}\right)} = \frac{1}{1 - j0,1} = \frac{1}{\sqrt{1^2 + (-0,1)^2}} = 0,995$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{-0,1}{1}\right)} = \frac{0°}{-5,71°} = 0° + 5,71° = +5,71°$$

$$Vo = (0,995).100\sin(100.t + 30° + \theta) = 99,5\sin(100.t + 35,71°)mV$$

# Langkah-langkah Perancangan HPF + 20 dB/decade

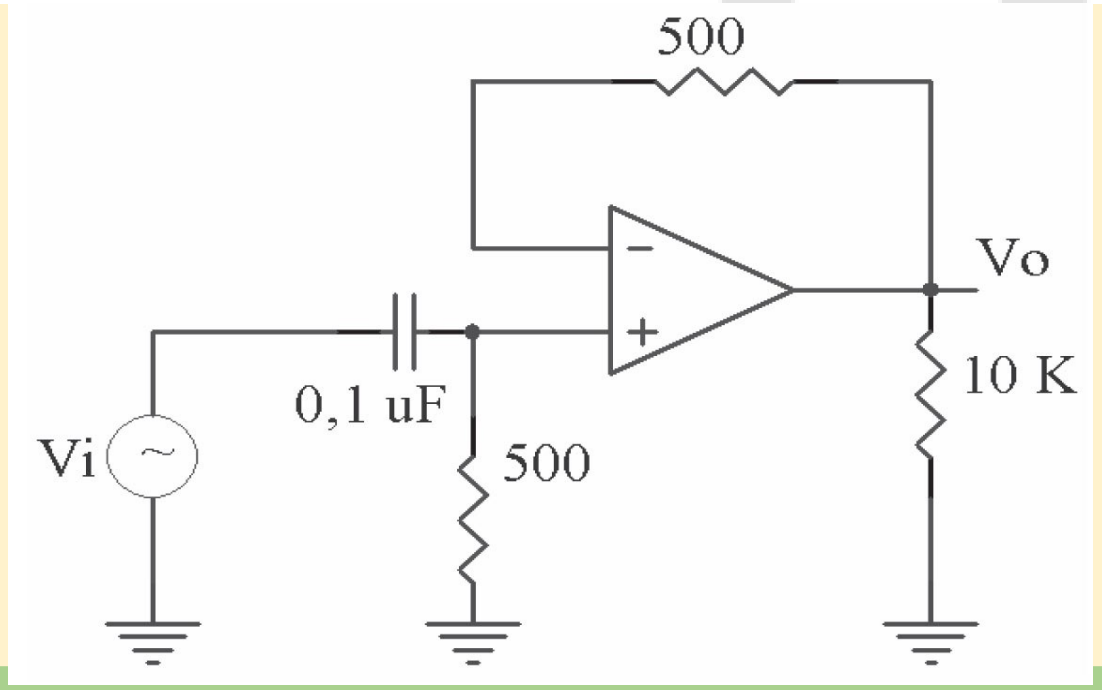
1. Pilihlah frekuensi *cut-off* () atau $\boldsymbol{f_c}$,
2. Pilihlah **C** antara 0,001 µF dan 0,1 µF,
3. Hitunglah **R** dengan rumus **R =**
4. Pilihlah **Rf = R**

**Contoh 6.9**

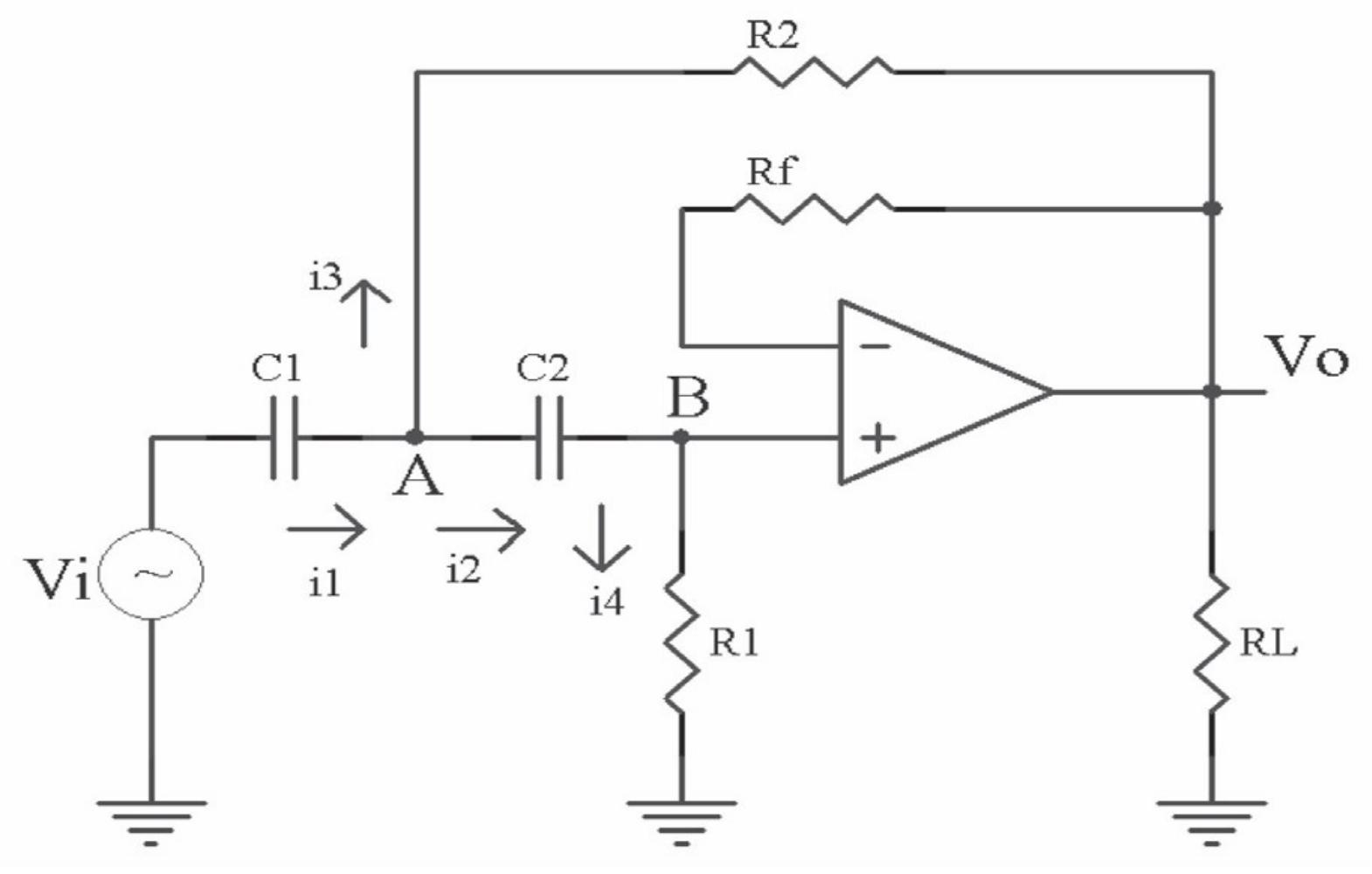
Rancanglah HPF +20 dB/dec dengan $\omega_c = 20krad/det$!

**Penyelesaian:**

1. Dipilih frekuensi *cut-off* $\omega_c = 20krad/det$
2. Dipilih C = 0,1 uF
3. Dihitung R yaitu $R = \frac{1}{\omega_c . C} = \frac{1}{2.10^4 . 10^{-7}} = 500\Omega$
4. Pilihlah Rf = 0,5 K



# Rangkaian HPF + 40 dB




Gambar 6.5 *Rangkaian HPF +40 dB/decade*

Pada titik A adalah $I1 = I2 + I3$

Pada titik B adalah $I2 = I4$

Tegangan **Vo** sama dengan tegangan

$$I4 = \frac{VB}{R1} = \frac{Vo}{R1}$$

$$I2 = \frac{VA - VB}{\frac{1}{j\omega.C2}} = (VA - Vo).j\omega C2$$

$$I2 = I4$$

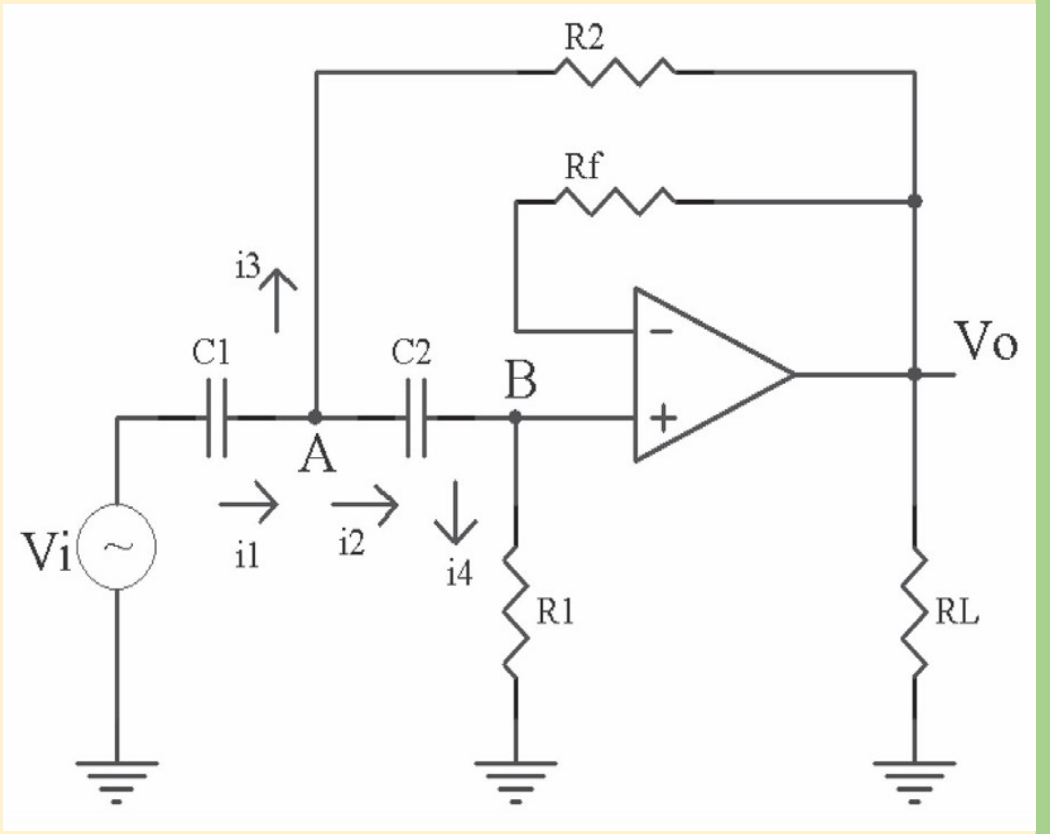
$$(VA - Vo).j\omega.C2 = \frac{Vo}{R1}$$

$$VA = Vo + \frac{Vo}{j\omega.C2.R1}$$

$$I1 = \frac{Vi - VA}{\frac{1}{j\omega.C1}} = (Vi - VA)\,j\omega.C1$$

$$I1 = \left( Vi - Vo - \frac{Vo}{j\omega.C2.R1} \right) j\omega.C1$$

$$I3 = \frac{VA - Vo}{R2}$$



$$I1 = I2 + I3$$

$$\left(Vi - Vo - \frac{Vo}{j\omega.C2.R1}\right) j\omega.C1 = (VA - Vo)\, j\omega.C2 + \frac{VA - Vo}{R2}$$

$$\left(Vi - Vo - \frac{Vo}{j\omega.C2.R1}\right) j\omega.C1 = \left(Vo + \frac{Vo}{j\omega.C2.R1} - Vo\right) j\omega.C2 + \frac{Vo + \frac{Vo}{j\omega.C2.R1} - Vo}{R2}$$

$$\left(Vi - Vo - \frac{Vo}{j\omega.C2.R1}\right) j\omega.C1 = \frac{Vo}{R1} + \frac{Vo}{j\omega.C2.R1.R2}$$

$$\left(Vi - Vo - \frac{Vo}{j\omega.C2.R1}\right) = \frac{Vo}{j\omega.C1.R1} + \frac{Vo}{-\omega^2.C1.C2.R1.R2}$$

$$Vi = Vo + \frac{Vo}{j\omega.C2.R1} + \frac{Vo}{j\omega.C1.R1} - \frac{Vo}{\omega^2.C1.C2.R1.R2}$$

$$Vi = Vo\left\{1 - \frac{1}{\omega^2.C1.C2.R1.R2} + \frac{1}{j\omega.R1}\left(\frac{1}{C1} + \frac{1}{C2}\right)\right\}$$

$$\frac{Vo}{V1} = \frac{1}{1 - \frac{1}{\omega^2.C1.C2.R1.R2} - j\frac{1}{\omega.R1}\left(\frac{1}{C1} + \frac{1}{C2}\right)}$$

$$\frac{Vo}{Vi} = \frac{1}{1 - \frac{1}{\omega^2 . C1.C2.R1.R2} - j\frac{1}{\omega.R1}\left(\frac{1}{C1} + \frac{1}{C2}\right)} \quad \ldots (6.33)$$

Pada HPF +40 dB/dec bahwa pada $\omega = \omega_c$ maka nilai penguatan $\left|\frac{Vo}{Vi}\right| = \frac{1}{\sqrt{2}} = 0{,}707$ dan sudut phasenya sama dengan $+90°$. Supaya menghasilkan nilai sudut phase seperti itu maka nilai sudut pada penyebut pada persamaan (6.33) sama dengan $-90°$. Supaya menghasilkan sudut $-90°$ maka nilai

$$1 - \frac{1}{\omega_c^2 . C1.C2.R1.R2} = 0 \text{ atau } \omega_c = \frac{1}{\sqrt{C1.C2.R1.R2}}$$

Apabila nilai kapasitor dibuat $C1 = C2 = C$ dan nilai resistor dibuat $R2 = \frac{1}{2}R1$ maka

$$\omega_c = \frac{1}{\sqrt{C.C.R1.\frac{1}{2}R1}} = \frac{1}{\sqrt{\frac{1}{2}C.R1}} = \frac{\sqrt{2}}{C.R1} = \frac{1{,}414}{C.R1}$$

atau nilai $R1 = \frac{\sqrt{2}}{\omega_c.C} = \frac{1{,}414}{\omega_c.C}$

Persamaan *transfer function* $\left|\frac{Vo}{Vi}\right|$ dari persamaan (6.33) sebagai fungsi $\omega_c$ menjadi:

$$\frac{Vo}{V1} = \frac{1}{1 - \frac{1}{\omega^2.C.C.\frac{\sqrt{2}}{\omega_c.C}.\frac{1}{2}.\frac{\sqrt{2}}{\omega_c.C}} - j\frac{1}{\omega.\frac{\sqrt{2}}{\omega_c.C}}\left(\frac{1}{C} + \frac{1}{C}\right)}$$

$$\frac{Vo}{V1} = \frac{1}{1 - \left(\frac{\omega_c}{\omega}\right) - j\sqrt{2}\left(\frac{\omega_c}{\omega}\right)}$$

Nilai penguatan $\left|\frac{Vo}{Vi}\right|$ dan sudut phase θ untuk beberapa nilai ω yang berbeda adalah

**Tabel 6.5** *Nilai penguatan dan sudut phase HPF +40 dB/dec*

| No. | Frekuensi (ω) | Penguatan ($\left\|\frac{Vo}{Vi}\right\|$) | Sudut Phase (θ) |
|---|---|---|---|
| 1 | $0{,}1\omega_c$ | 0,0099995302 | +171,87° |
| 2 | $0{,}25\omega_c$ | 0,0623794998 | +159,34° |
| 3 | $0{,}5\omega_c$ | 0,2425528612 | +136,69° |
| 4 | $\omega_c$ | $\frac{1}{\sqrt{2}}$ atau 0,707 | +90° |
| 5 | $2\omega_c$ | 0,9702338206 | +43,31° |
| 6 | $4\omega_c$ | 0,9980713439 | +20,66° |
| 7 | $10\omega_c$ | 0,9999500037 | +8,13° |

**Contoh 6.10**

Hitunglah frekuensi *cut-off* ($\omega_c$) pada Gambar 6.5 apabila nilai R1 = 10K, R2 = 100K, C1 = 10 nF, C2 = 100 nF, Rf = 100K, RL = 10K!

**Penyelesaian:** Nilai frekuensi *cut-off* ($\omega_c$) dari LPF +40 dB/dec adalah $\omega_c = \frac{1}{\sqrt{C1.C2.R1.R2}}$

$$\omega_c = \frac{1}{\sqrt{10^{-8}.10^{-7}.10^{4}.10^{5}}} = \frac{1}{\sqrt{10^{-6}}} = \frac{1}{10^{-3}} = 1000 \text{rad/s}$$

**Contoh 6.11**

Hitunglah frekuensi *cut-off* ($\omega_c$) pada Gambar 6.5 apabila nilai C1 = C2 = C = 100 nF, R1 = 10 K, R2 = 0,5R1 = 5 K, Rf = 10K, RL = 10K. Apabila $Vi = 100\sin(\omega.t + 60^o)mV$, hitunglah Vo pada frekuensi $0{,}1\omega_c$, $0{,}25\omega_c$, $0{,}5\omega_c$, $\omega_c$, $2\omega_c$, $4\omega_c$, $10\omega_c$.

**Penyelesaian:** Karena nilai C1 = C2 = C dan R2 = 0,5R1 maka nilai frekuensi *cut-off* ($\omega_c$) dari

HPF +40 dB/dec adalah $\omega_c = \dfrac{1{,}414}{C.R1}$

$$\omega_c = \frac{1{,}414}{10^{-7}.10^4} = 1414 \text{rad/s} = 1{,}414 \text{Krad/s}$$

$$\omega_c = \frac{1,414}{10^{-7}.10^4} = 1414 rad/s = 1,414 Krad/s$$

Untuk $\omega = 0,1\omega_c = 141,4 rad/s$,

$$\frac{Vo}{V1} = \frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2 - j\sqrt{2}\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1-\left(\frac{\omega_c}{0,1\omega}\right)^2 - j\sqrt{2}\left(\frac{\omega_c}{0,1\omega}\right)} = \frac{1}{1-100-j14,14}$$

$$\left|\frac{Vo}{V1}\right| = \frac{1}{\sqrt{(-2)^2+14,14^2}} = \frac{1}{\sqrt{9801+199,94}} = 0,009$$

$$\theta = \frac{0^\circ}{tg^{-1}\left(\frac{-14,14}{-99}\right)} = \frac{0^\circ}{-171,87^\circ} = 0^\circ + 171,87^\circ = +171,87^\circ$$

$$Vo = (0,009).100\sin(141,4.t + 60^\circ + \theta) = 0,9\sin(141,4.t + 231,87^\circ) mV$$

Untuk $\omega = 0{,}25\omega_c = 353{,}5 rad/s$,

$$\frac{Vo}{V1} = \frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2 - j\sqrt{2}\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1-\left(\frac{\omega_c}{0{,}25\omega}\right)^2 - j\sqrt{2}\left(\frac{\omega_c}{0{,}25\omega}\right)} = \frac{1}{1-16-j5{,}656}$$

$$\left|\frac{Vo}{V1}\right| = \frac{1}{\sqrt{(-15)^2 + -5{,}656^2}} = \frac{1}{\sqrt{225+32}} = 0{,}062$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{-5{,}656}{-15}\right)} = \frac{0°}{-159{,}34°} = 0° + 159{,}34° = +159{,}34°$$

$$Vo = (0{,}062).100\sin(353{,}5.t + 60° + \theta) = 6{,}2\sin(353{,}5.t + 219{,}34°)mV$$

Untuk $\omega = 0{,}5\omega_c = 707 rad/s$,

$$\frac{Vo}{V1} = \frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2 - j\sqrt{2}\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1-\left(\frac{\omega_c}{0{,}5\omega}\right)^2 - j\sqrt{2}\left(\frac{\omega_c}{0{,}5\omega}\right)} = \frac{1}{1-4-j2{,}828}$$

$$\left|\frac{Vo}{V1}\right| = \frac{1}{\sqrt{(-3)^2 + (-2{,}828)^2}} = \frac{1}{\sqrt{9+7{,}998}} = 0{,}242$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{-2{,}828}{-3}\right)} = \frac{0°}{-136{,}69°} = 0° + 136{,}69° = +136{,}69°$$

$$Vo = (0{,}242).100\sin(707.t + 60° + \theta) = 24{,}2\sin(707.t + 196{,}69°)mV$$

Untuk $\omega = \omega_c = 1414 rad/s$,

$$\frac{Vo}{V1} = \frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2 - j\sqrt{2}\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2 - j\sqrt{2}\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1-1+j\sqrt{2}} = \frac{1}{-j\sqrt{2}}$$

$$\left|\frac{Vo}{V1}\right| = \frac{1}{\sqrt{0^2+\left(-\sqrt{2}\right)^2}} = \frac{1}{\sqrt{2}} = 0,707$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{-\sqrt{2}}{0}\right)} = \frac{0°}{-90°} = 0° + 90° = +90°$$

$$Vo = (0,707).100\sin(1414.t + 60° + \theta) = 70,7\sin(1414.t + 150°)mV$$

Untuk $\omega = 2\omega_c = 2828 rad/s$,

$$\frac{Vo}{V1} = \frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2 - j\sqrt{2}\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1-\left(\frac{\omega_c}{2\omega}\right)^2 - j\sqrt{2}\left(\frac{\omega_c}{2\omega}\right)} = \frac{1}{1-0,25+j0,707}$$

$$\left|\frac{Vo}{V1}\right| = \frac{1}{\sqrt{(0,75)^2+(-0,707)^2}} = \frac{1}{\sqrt{0,5625+0,4998}} = 0,97$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{-0,707}{0,75}\right)} = \frac{0°}{-43,31°} = 0° + 43,31° = +43,31°$$

$$Vo = (0,97).100\sin(2828.t + 60° + \theta) = 97\sin(2828.t + 103,31°)mV$$

Untuk $\omega = 4\omega_c = 5656 rad/s$,

$$\frac{Vo}{V1} = \frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2 - j\sqrt{2}\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1-\left(\frac{\omega_c}{4\omega}\right)^2 - j\sqrt{2}\left(\frac{\omega_c}{4\omega}\right)} = \frac{1}{1-0{,}0625 + j0{,}3535}$$

$$\left|\frac{Vo}{V1}\right| = \frac{1}{\sqrt{(0{,}9375)^2 + (-0{,}3535)^2}} = \frac{1}{\sqrt{0{,}8789 + 0{,}125}} = 0{,}998$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{-0{,}3535}{0{,}9375}\right)} = \frac{0°}{-20{,}66°} = 0° + 20{,}66° = +20{,}66°$$

$$Vo = (0{,}998).100\sin(5656.t + 60° + \theta) = 99{,}8\sin(5656.t + 80{,}66°)mV$$

Untuk $\omega = 10\omega_c = 14140 rad/s$,

$$\frac{Vo}{V1} = \frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2 - j\sqrt{2}\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1-\left(\frac{\omega_c}{10\omega}\right)^2 - j\sqrt{2}\left(\frac{\omega_c}{10\omega}\right)} = \frac{1}{1-0{,}01 + j0{,}1414}$$

$$\left|\frac{Vo}{V1}\right| = \frac{1}{\sqrt{(0{,}99)^2 + (-0{,}1414)^2}} = \frac{1}{\sqrt{0{,}9801 + 0{,}02}} = 0{,}999$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{-0{,}1414}{0{,}99}\right)} = \frac{0°}{-8{,}13°} = 0° + 8{,}13° = +8{,}13°$$

$$Vo = (0{,}999).100\sin(14140.t + 60° + \theta) = 99{,}9\sin(14140.t + 68{,}13°)mV$$

# Langkah-langkah Perancangan HPF + 40 dB/decade

1. Pilihlah frekuensi *cut-off* () atau $f_c$,
2. Pilihlah **C1=C2=C** antara 0,001 µF dan 0,1 µF,
3. Hitunglah **R1** dengan rumus **R1 =**
4. Pilihlah **R2 = 0,5.R1**
5. Pilihlah **Rf = R1**

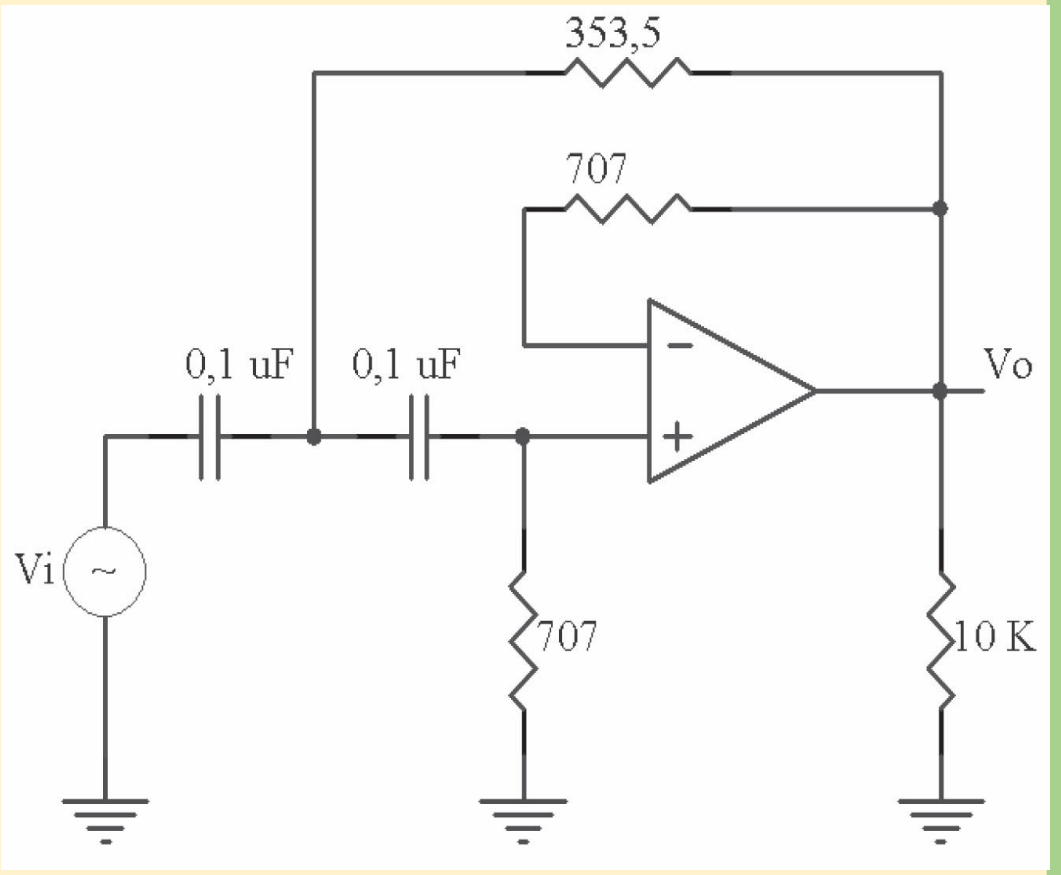
**Contoh 6.12**

Rancanglah HPF +40dB/dec dengan $\omega_c = 20krad/det$!

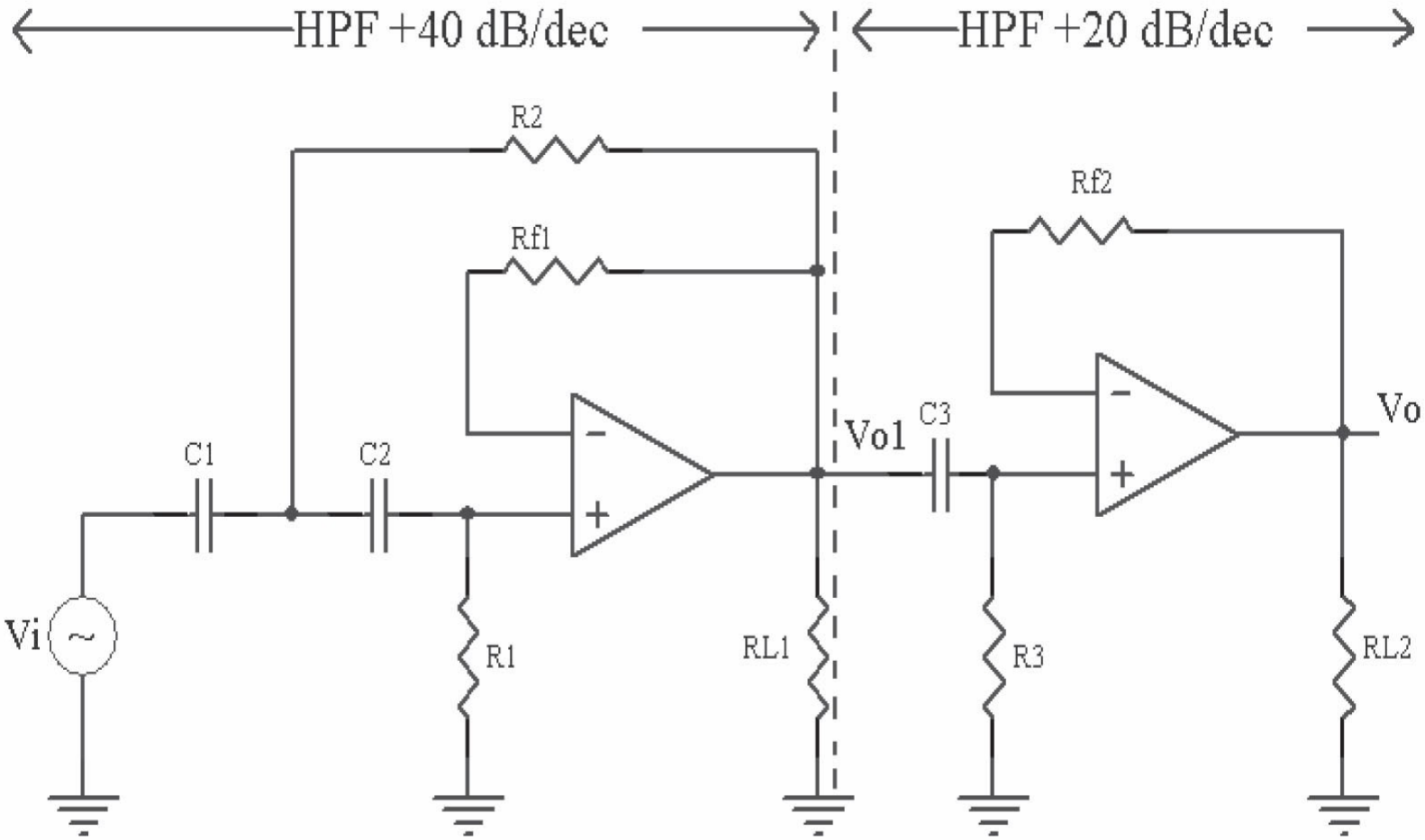
**Penyelesaian:**

1. Dipilih frekuensi *cut-off* $\omega_c = 20krad/det$
2. Dipilih C1 = C2 = C = 0,1 uF
3. Dihitung R1 yaitu $R1 = \frac{1,414}{\omega_c.C} = \frac{1,414}{2.10^4.10^{-7}} = 707\Omega$
4. Pilihlah R2 = 0,5.R1 yaitu R2 = 353,5
5. Pilihlah Rf = R1 = 707.

   Rangkaian HPF +40 dB/dec dengan $\omega_c = 20krad/det$



# Rangkaian HPF + 60 dB




Gambar 6.6 *Rangkaian HPF +60 dB/decade*

Analisis dari rangkaian filter HPF +60 dB/dec bahwa penguatan keseluruhan dari rangkaian adalah:

$$\frac{Vo}{Vi}=\frac{Vo1}{Vi}\times\frac{Vo}{Vo1} \tag{38}$$

$$\frac{Vo}{Vi}=\frac{1}{1-\frac{1}{\omega^2.C1.C2.R1.R2}-j\frac{1}{\omega.R1}\left(\frac{1}{C1}+\frac{1}{C2}\right)}\times\frac{1}{1-j\frac{1}{\omega.C3.R3}}$$

Pada HPF +60 dB/dec bahwa pada frekuensi $\omega=\omega_c$ maka nilai $\left|\frac{Vo}{Vi}\right|=\frac{1}{\sqrt{2}}=0{,}707$ dan sudut phasenya sebesar +135°. Apabila nilai C1 = C2 = C3 = C, R1 = 2.R3, R2 = 0,5.R3 maka besarnya frekuensi *cut-off*

$$\omega_c=\frac{1}{C.R3} \text{ atau } R3=\frac{1}{\omega_c.C} \tag{39}$$

Persamaan (6.38) atau *transfer function* $\left|\frac{Vo}{Vi}\right|$ yang merupakan fungsi dari $\omega_c$ menjadi:

$$\frac{Vo}{Vi}=\frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2-j\sqrt{2}\left(\frac{\omega_c}{\omega}\right)}\times\frac{1}{1-j\left(\frac{\omega_c}{\omega}\right)} \tag{40}$$

Nilai penguatan $\left|\frac{Vo}{Vi}\right|$ dan sudut phase θ untuk beberapa nilai ω yang berbeda adalah

**Tabel 6.6** *Nilai penguatan dan sudut phase HPF +60 dB/dec*

| No. | Frekuensi (ω) | Penguatan HPF + 20 dB/dec | Sudut phase (θ) HPF + 20 dB/dec | Penguatan HPF + 40 dB/dec | Sudut phase (θ) HPF + 40 dB/dec | Penguatan HPF + 60 dB/dec | Sudut phase (θ) HPF + 60 dB/dec |
|---|---|---|---|---|---|---|---|
| 1 | $0{,}1\omega_c$ | 0,0995037190 | +84,29° | 0,0099995302 | +171,87° | 0,0009949904 | +256,16° |
| 2 | $0{,}25\omega_c$ | 0,2425356250 | +75,96° | 0,0623794998 | +159,34° | 0,0151292509 | +235,3° |
| 3 | $0{,}5\omega_c$ | 0,4472135955 | +63,43° | 0,2425528612 | +136,69° | 0,1084729371 | +200,12° |
| 4 | $\omega_c$ | $\frac{1}{\sqrt{2}}$ atau 0,707 | +45° | $\frac{1}{\sqrt{2}}$ atau 0,707 | +90° | $\frac{1}{\sqrt{2}}$ atau 0,707 | +135° |
| 5 | $2\omega_c$ | 0,8944271909 | +26,56° | 0,9702338206 | +43,31° | 0,8678035107 | +69,87° |
| 6 | $4\omega_c$ | 0,9701425001 | +14,04° | 0,9980713439 | +20,66° | 0,9682714288 | +34,7° |
| 7 | $10\omega_c$ | 0,9950371902 | +5,71° | 0,9999500037 | +8,13° | 0,9949874420 | +13,84° |

**Contoh 6.13**

Hitunglah frekuensi *cut-off* ($\omega_c$) pada Gambar 5.6 apabila nilai C1 = C2 = C3 = C = 100nF, R3 = 20 K, R1 = 2. R3 = 40 K, R2 = 0,5.R3 = 10 K, Rf1 = Rf2 = 10K, RL = 10K!

Apabila $Vi = 100\sin(\omega.t + 60^o)mV$, hitunglah Vo pada frekuensi $0{,}1\omega_c$, $0{,}25\omega_c$, $0{,}5\omega_c$, $\omega_c$, $2\omega_c$, $4\omega_c$, $10\omega_c$!

**Penyelesaian:** Karena nilai C1 = C2 = C3 = C = 100 nF dan R3 = 20 K, R1 = 2R3, R2 = 0,5R3 maka nilai frekuensi *cut-off* ($\omega_c$) dari HPF +60 dB/dec adalah $\omega_c = \dfrac{1}{C.R3}$

$$\omega_c = \frac{1}{10^{-7}.2.10^4} = 500 \text{rad/s}$$

Untuk $\omega = 0{,}1\omega_c = 50\text{rad/s}$,

$$\frac{Vo}{Vi} = \frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2 - j\sqrt{2}.\left(\frac{\omega_c}{\omega}\right)} \times \frac{1}{1-j\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1-\left(\frac{\omega_c}{0{,}1\omega_c}\right)^2 - j\sqrt{2}.\left(\frac{0{,}1\omega_c}{0{,}1\omega_c}\right)} \times \frac{1}{1-j\left(\frac{\omega_c}{0{,}1\omega_c}\right)}$$

$$\frac{Vo}{Vi} = \frac{1}{(-99)^2 + (-14{,}14)^2} \times \frac{1}{1^2 - j(-10)^2} =$$

$$\left|\frac{Vo}{Vi}\right| = \frac{1}{\sqrt{0{,}99^2 + 0{,}1414^2}} \times \frac{1}{\sqrt{1^2 + 0{,}1^2}} = 0{,}001$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{-0{,}1414}{-0{,}99}\right) + tg^{-1}\left(\frac{-10}{1}\right)} = \frac{0°}{-171{,}87° + (-84{,}29)°} = 0° + 256{,}16° = +256{,}16°$$

$$Vo = (0{,}001).100\sin(50.t + 60° + \theta) = 0{,}1\sin(50.t + 316{,}16°)mV$$

Untuk $\omega = 0{,}25\omega_c = 125 rad/s$,

$$\frac{Vo}{Vi} = \frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2 - j\sqrt{2}.\left(\frac{\omega_c}{\omega}\right)} \times \frac{1}{1-j\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1-\left(\frac{\omega_c}{0{,}25\omega_c}\right)^2 - j\sqrt{2}.\left(\frac{0{,}1\omega_c}{0{,}25\omega_c}\right)} \times \frac{1}{1-j\left(\frac{\omega_c}{0{,}25\omega_c}\right)}$$

$$\frac{Vo}{Vi} = \frac{1}{1-(4)^2 - j\sqrt{2}.(4)} \times \frac{1}{1-j(4)} =$$

$$\left|\frac{Vo}{Vi}\right| = \frac{1}{\sqrt{(-15)^2+(-5{,}656)^2}} \times \frac{1}{\sqrt{1^2+(-4)^2}} = 0{,}015$$

$$\theta = \frac{0^\circ}{tg^{-1}\left(\frac{-5{,}656}{-15}\right)+tg^{-1}\left(\frac{-4}{1}\right)} = \frac{0^\circ}{-159{,}34^\circ + (-75{,}96)^\circ} = 0^\circ + 235{,}3^\circ = +235{,}3^\circ$$

$$Vo = (0{,}015).100\sin(125.t + 60^\circ + \theta) = 1{,}5\sin(125.t + 295{,}3^\circ)mV$$

Untuk $\omega = 0{,}5\omega_c = 250\text{rad/s}$,

$$\frac{Vo}{Vi} = \frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2 - j\sqrt{2}.\left(\frac{\omega_c}{\omega}\right)} \times \frac{1}{1-j\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1-\left(\frac{\omega_c}{0{,}5\omega_c}\right)^2 - j\sqrt{2}.\left(\frac{0{,}1\omega_c}{0{,}5\omega_c}\right)} \times \frac{1}{1-j\left(\frac{\omega_c}{0{,}5\omega_c}\right)}$$

$$\frac{Vo}{Vi} = \frac{1}{1-(2)^2 - j\sqrt{2}.(2)} \times \frac{1}{1-j(2)} =$$

$$\left|\frac{Vo}{Vi}\right| = \frac{1}{\sqrt{(-3)^2 + (-2{,}828)^2}} \times \frac{1}{\sqrt{1^2 + (-2)^2}} = 0{,}108$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{0{,}707}{0{,}75}\right) + tg^{-1}\left(\frac{0{,}5}{1}\right)} = \frac{0°}{-136{,}69° + (-63{,}44)°} = 0° + 200{,}12° = +200{,}12°$$

$$Vo = (0{,}108).100\sin(250.t + 60° + \theta) = 10{,}8\sin(250.t + 260{,}12°)mV$$

Untuk $\omega = \omega_c = 500 rad/s$,

$$\frac{Vo}{Vi} = \frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2 - j\sqrt{2}.\left(\frac{\omega_c}{\omega}\right)} \times \frac{1}{1-j\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1-\left(\frac{\omega_c}{\omega_c}\right)^2 - j\sqrt{2}.\left(\frac{0,1\omega_c}{\omega_c}\right)} \times \frac{1}{1-j\left(\frac{\omega_c}{\omega_c}\right)}$$

$$\frac{Vo}{Vi} = \frac{1}{1-(1)^2 - j\sqrt{2}.(1)} \times \frac{1}{1-j(1)} =$$

$$\left|\frac{Vo}{Vi}\right| = \frac{1}{\sqrt{0^2+\left(-\sqrt{2}\right)^2}} \times \frac{1}{\sqrt{1^2+(-1)^2}} = \frac{1}{\sqrt{2}} \times \frac{1}{\sqrt{2}} = 0,5$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{-\sqrt{2}}{0}\right) + tg^{-1}\left(\frac{-1}{1}\right)} = \frac{0°}{-90° + (-45)°} = 0° + 135° = +135°$$

$$Vo = (0,5).100\sin(500.t + 60° + \theta) = 50\sin(500.t + 195°)mV$$

Untuk $\omega = 2\omega_c = 1000 rad/s$,

$$\frac{Vo}{Vi} = \frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2 - j\sqrt{2}.\left(\frac{\omega_c}{\omega}\right)} \times \frac{1}{1-j\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1-\left(\frac{\omega_c}{2\omega_c}\right)^2 - j\sqrt{2}.\left(\frac{0,1\omega_c}{2\omega_c}\right)} \times \frac{1}{1-j\left(\frac{\omega_c}{2\omega_c}\right)}$$

$$\frac{Vo}{Vi} = \frac{1}{1-(1)^2 - j\sqrt{2}.(1)} \times \frac{1}{1-j(1)} =$$

$$\left|\frac{Vo}{Vi}\right| = \frac{1}{\sqrt{0,75^2 + (-0,707)^2}} \times \frac{1}{\sqrt{1^2 + (-0,5)^2}} = 0,868$$

$$\theta = \frac{0^o}{tg^{-1}\left(\frac{-0,707}{0,75}\right) + tg^{-1}\left(\frac{-0,5}{1}\right)} = \frac{0^o}{-43,31^o + (-26,56)^o} = 0^o + 69,87^o = +69,87^o$$

$$Vo = (0,868).100\sin(1000.t + 60^o + \theta) = 86,8\sin(1000.t + 129,87^o)mV$$

Untuk $\omega = 4\omega_c = 2000 \text{rad/s}$,

$$\frac{Vo}{Vi} = \frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2 - j\sqrt{2}\left(\frac{\omega_c}{\omega}\right)} \times \frac{1}{1-j\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1-\left(\frac{\omega_c}{4\omega_c}\right)^2 - j\sqrt{2}\left(\frac{0{,}1\omega_c}{4\omega_c}\right)} \times \frac{1}{1-j\left(\frac{\omega_c}{4\omega_c}\right)}$$

$$\frac{Vo}{Vi} = \frac{1}{1-(0{,}25)^2 - j\sqrt{2}\,(0{,}25)} \times \frac{1}{1-j(0{,}25)}$$

$$\left|\frac{Vo}{Vi}\right| = \frac{1}{\sqrt{(0{,}9375)^2 + (-0{,}3535)^2}} \times \frac{1}{\sqrt{1^2 + (-0{,}25)^2}} = 0{,}968$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{-0{,}3535}{0{,}9375}\right) + tg^{-1}\left(\frac{-0{,}25}{1}\right)} = \frac{0°}{-20{,}66° + (-14{,}04)°} = 0° + 34{,}7° = +34{,}7°$$

$$Vo = (0{,}968).100\sin(2000.t + 60° + \theta) = 96{,}8\sin(2000.t + 94{,}7°)mV$$

Untuk $\omega = 10\omega_c = 5000 rad/s$,

$$\frac{Vo}{Vi} = \frac{1}{1-\left(\frac{\omega_c}{\omega}\right)^2 - j\sqrt{2}.\left(\frac{\omega_c}{\omega}\right)} \times \frac{1}{1-j\left(\frac{\omega_c}{\omega}\right)} = \frac{1}{1-\left(\frac{\omega_c}{10\omega_c}\right)^2 - j\sqrt{2}.\left(\frac{0,1\omega_c}{10\omega_c}\right)} \times \frac{1}{1-j\left(\frac{\omega_c}{10\omega_c}\right)}$$

$$\left|\frac{Vo}{Vi}\right| = \frac{1}{\sqrt{(0,99)^2+(-0,1414)^2}} \times \frac{1}{\sqrt{1^2+(-0,1)^2}} = 0,999$$

$$\theta = \frac{0°}{tg^{-1}\left(\frac{-0,1414}{0,99}\right)+tg^{-1}\left(\frac{-0,1}{1}\right)} = \frac{0°}{-8,13° + (-5,71)°} = 0° + 13,84° = +13,84°$$

$$Vo = (0,999).100\sin(5000.t + 60° + \theta) = 99,9\sin(2000.t + 73,84°)mV$$

# Langkah-langkah Perancangan HPF + 60 dB/decade

1. Pilihlah frekuensi *cut-off* () atau $f_c$,
2. Pilihlah **C1=C2=C3=C** antara 0,001 µF dan 0,1 µF,
3. Hitunglah **R3** dengan rumus **R3 =**
4. Pilihlah **R1 = 0,5.R3**
5. Pilihlah **R2 = 2.R3**
6. Pilihlah **Rf 1= R2 dan Rf 2= R3**

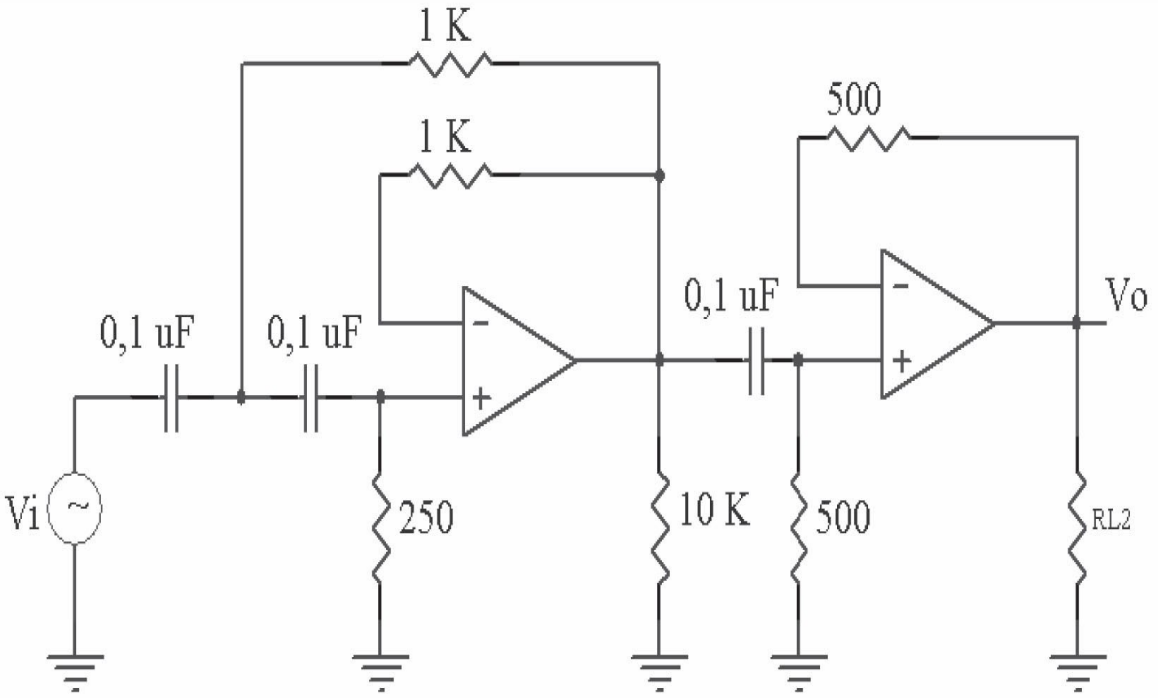
**Contoh 6.14**

Rancanglah HPF +60dB/dec dengan $\omega_c$ = 20*krad/det*!

**Penyelesaian:**

1. Dipilih frekuensi *cut-off* $\omega_c$ = 20*krad/det*
2. Dipilih C1 = C2 = C3 = 0,1 uF
3. Dihitung R3 yaitu $R3 = \frac{1}{\omega_c . C} = \frac{1}{2.10^4 . 10^{-7}} = 500\Omega$
4. Pilihlah R1 = 0,5. R3 yaitu R1 = 250
5. Pilihlah R2 = 2 . R3 = 1 K
6. Pilihlah Rf1 = 1 K dan Rf2 = 500.

   Rangkaian filter HPF +60 dB/dec dengan $\omega_c$ = 20*krad/det*



https://www.its.ac.id/telektro/id/beranda/